

Platforms, Orbits and Sensors

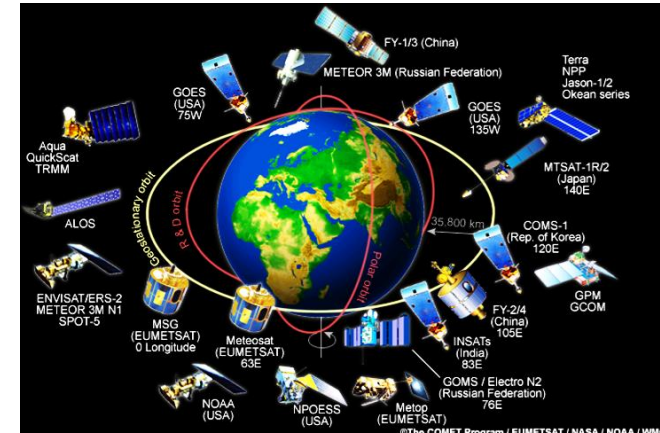
Platforms

- Ground based
- Air-borne
- Space-borne -
Rockets, space
shuttles, satellites



LEO ~ 1000 km
SSO ~ 600-800 km
GEO ~ 36000 km

Airborne systems
- high spatial resolution
- not suitable for
repeated observations
& wide area coverage



Advantages of Satellite RS

- Synoptic View
- Global picture - movement of sat over rotating earth
- Repeated Observation (Time series data - Change detection)
- Inaccessible area - mountain, desert, ocean, atm, polar region

Limitations – As height increases, spatial resolution become poor

Classification of Satellite Orbits

➤ Shape of orbit

- Circular - center of earth as center
- Elliptical - earth's center as one of the foci

➤ Plane of orbit

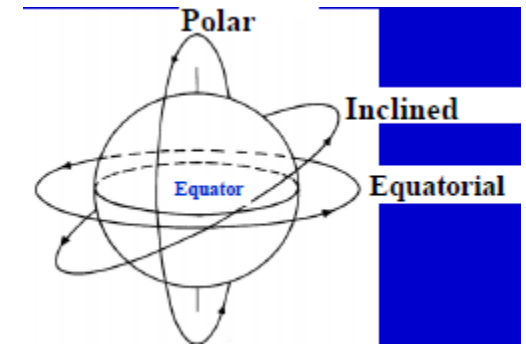
- Equatorial orbit - above earth's equator
- Polar orbit - passes over both poles
- Inclined orbits

➤ Altitude

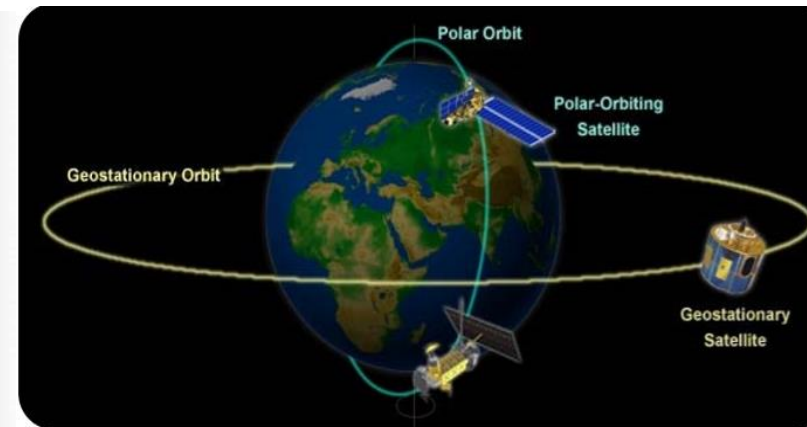
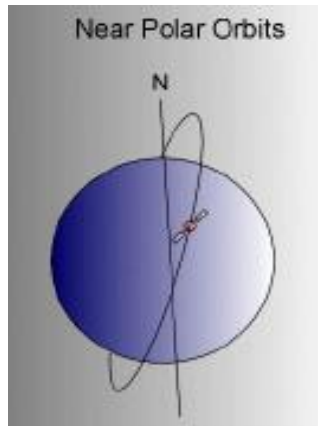
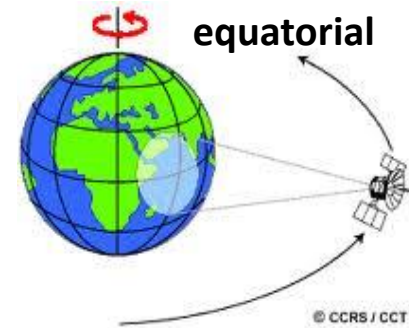
- Low earth orbit (LEO) - ~ 1000 km
- Geostationary orbit (GEO) - ~ 36,000 km
- Medium earth orbit (MEO) - ~ 20,000 km
- Molniya orbit – inclined and elliptical

Remote sensing

- LEO circular ~ 1,000 km
- SSO near polar ~ 600-800 km
- GEO Eq. circular ~ 36,000 km



Polar circular



Sat remains in orbit → balance between centrifugal force and earth's gravitational pull.

$$\frac{mv^2}{a} = \frac{GMm}{a^2}$$

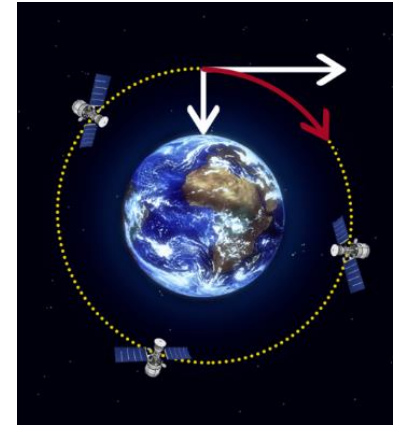
m - mass of sat, M - mass of earth = 5.974×10^{24} kg

a - distance between sat and center of earth (r+h) v - velocity

G - universal gravitational constant = $6.672 \times 10^{-11} \text{ m}^3\text{kg}^{-1}\text{s}^{-2}$

$$v^2 = \frac{GM}{a}, \dots v = \sqrt{\frac{GM}{a}}$$

$$\text{Period}..P = \frac{2.\pi.a}{v} = \frac{2.\pi.a}{\sqrt{GM/a}} = \frac{2.\pi.a^{3/2}}{\sqrt{GM}}$$

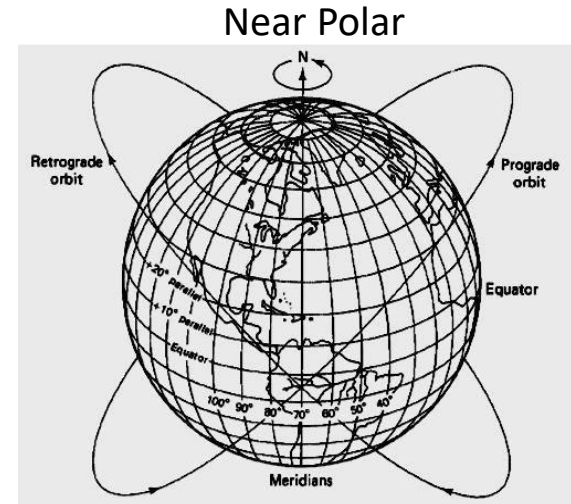


As height increases, velocity decreases and period increases

Height above Earth Km	linear vel in orbit km/s	Time period in minute	No. of rotations per day	Type
1,000	7.35	105	$\cong 14$	LEO RS
35,786	3.18	23h 56m	$\cong 1$	GEO

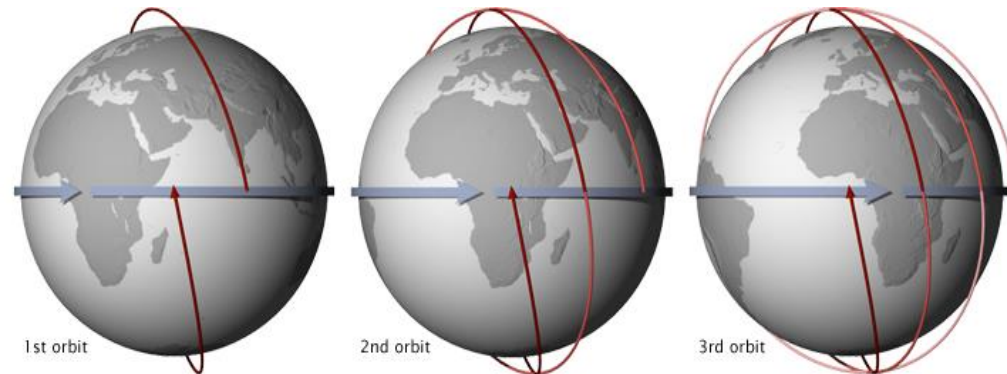
Low Earth Orbit (LEO) satellites:

- ≈ 1000 km above surface of earth.
- ≈ 7.35 km/s
- ≈ 105 minutes/ revolution
- ≈ 14 revolutions/day
- visible from a location for ~ 10 min
- As sat moves around earth, earth rotates on its axis $\rightarrow$ same area will be seen only after a period of time $\rightarrow$ repetitivity



LEO - Advantages

- Global coverage
- High spatial resolution



LEO - Disadvantages

- Poor temporal resolution for RS
- Short time visibility over an area
- Lifetime reduces - atm drag

Sub-satellite point

Sub-satellite path (ground track) - Path traced out on earth surface directly below sat.
Westward shift of ground track due to rotation of earth → global coverage

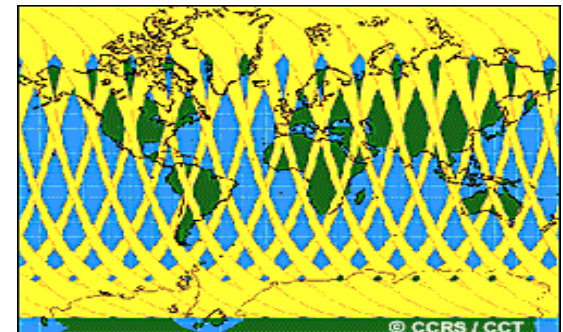
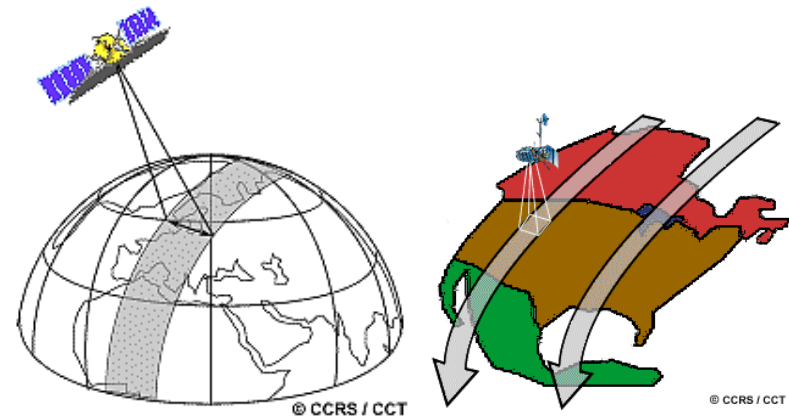
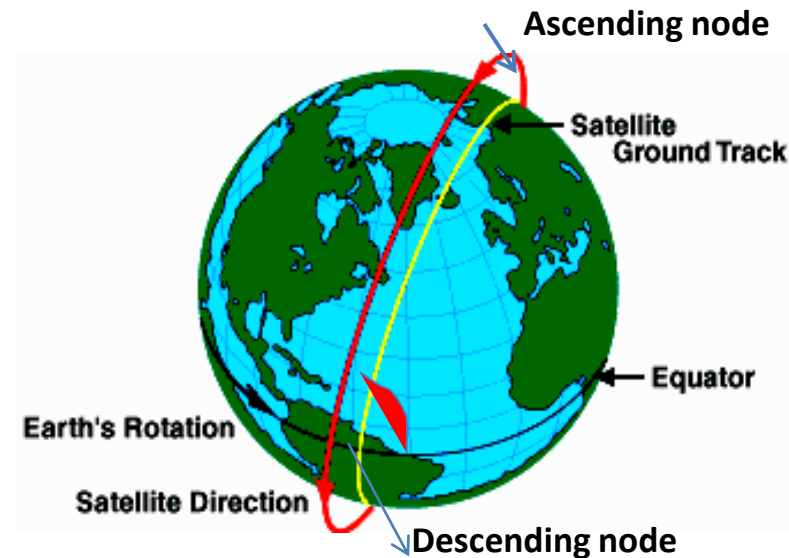
Descending node - point where orbit crosses equatorial plane going from N to S.

Ascending node - point where orbit crosses equatorial plane going from S to N.

Inclination - Angle between orbital plane and earth's equatorial plane.

Greatest lat reached by sub-satellite path → inclination limits range of latitude.

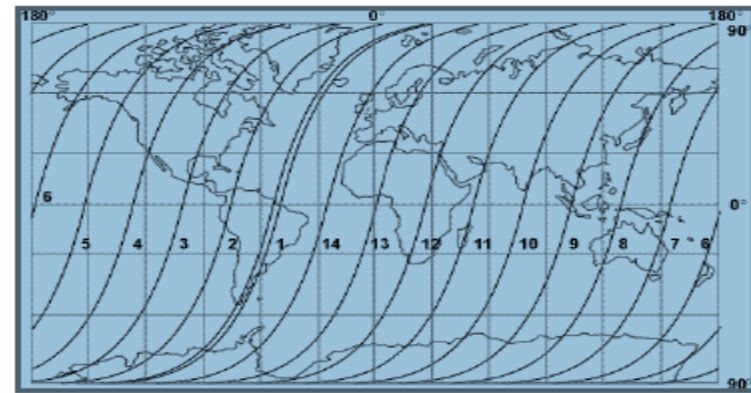
Swath - As satellite revolves around Earth, sensor sees a certain portion of Earth's surface → vary upto thousands of km wide.



SunSynchronous orbit (SSO)

Near polar orbit

Orbits are designed such that satellite's orientation is fixed relative to Sun throughout the year → they cover each area of world at a constant local time of day - Synchronous with illumination condition



Complete coverage of earth by sun synchronous orbit

Whenever the satellite observes a given ground scene, the Sun is always in the same location in the sky.

satellite's orientation is fixed relative to the Sun throughout the year

Orbital plane is rotated at same rate as earth's revolution around sun - approximately 1° eastward each day

Achieved by adjusting height and inclination

Sun synchronous orbit parameters are chosen depending on swath to generate complete coverage during a coverage cycle

Sun-synchronous orbits around Earth are about 600-800 km in altitude, with periods of about 96-100 minute, and inclinations of around 98° .

Geosynchronous Orbits

Revolution period around earth = earth rotation period about its axis

$$\text{Period..}P = \frac{2.\pi.a}{v} = \frac{2.\pi.a}{\sqrt{GM / a}} = \frac{2.\pi.a^{3/2}}{\sqrt{GM}} \quad p^2 = \frac{(2.\pi)^2 .a^3}{GM}$$

$$P^2 \propto a^3 \quad a = A P^{2/3} \quad A = 42,241.7$$

- For $P = 23\text{h } 56\text{m and } 4\text{S}$ (Sidereal day), $a = (r+h) \rightarrow 42,164 \text{ km}$
- Height above earth surface - $35,786 \text{ km}$, $\approx 36,000 \text{ km}$.
- Geosynchronous - orbit with period of revolution = 1 sidereal day

Geostationary orbit

Sat appears to be stationary with respect to Earth.

- Sat must travel at same rotational speed of Earth

$\rightarrow 23\text{h}, 56\text{m}, 4\text{S}$

From center of earth - $42,164 \text{ km}$,

Above earth surface - $35,786 \text{ km}$ ($\approx 36,000 \text{ km}$).

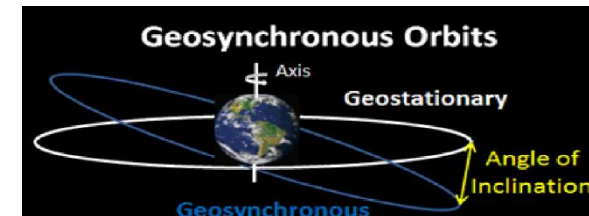
- Inclination of orbit must be zero (earth's equatorial plane)

Any inclination cause sat to move N-S directions.

- Revolve in same direction as that of earth ($W \rightarrow E$).

- Orbit must be circular. Earth is rotating with a constant speed, for a sat to appear stationary it has to move at same speed.

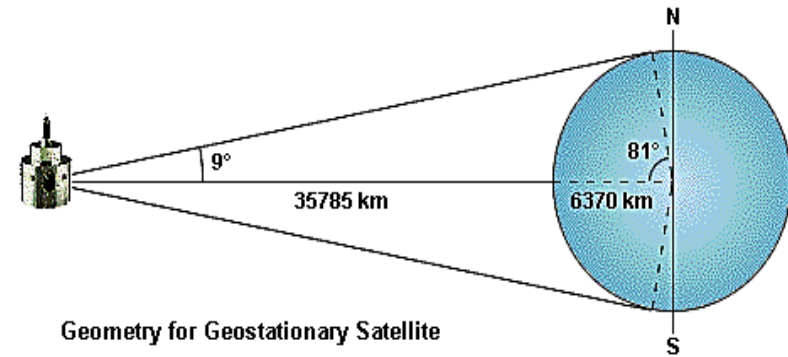
- Only 1 value of 'a' satisfies Kepler's 3rd law $\rightarrow$ only 1 geo orbit.



- All geosynchronous sat are not geostationary
- All geostationary sat are geosynchronous

GEO – Advantages

- Large coverage area - almost 42% of equatorial region. 3 sat. at 120° apart cover whole earth upto 81°N & $^\circ\text{S}$
- Continuous view of a particular area



GEO orbits are highly useful for satellite communication & weather monitoring → provide constant view of the same surface area.



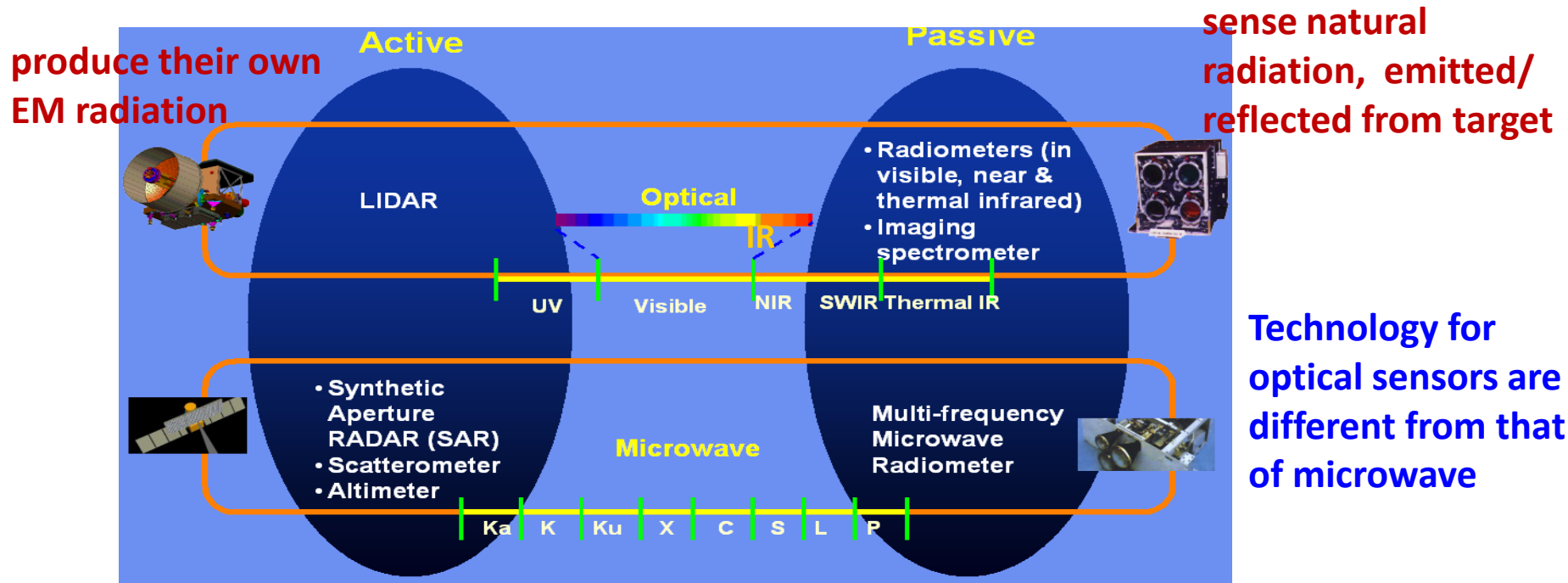
GEO - Disadvantages

- Poor spatial resolution
- Polar regions cannot be seen by GEOs

INSAT, GSAT,
INTELSAT,
METEOSAT,

Classification of Remote Sensors

Remote sensors measure reflection or emission properties of EM radiation from a surface/ medium → radiance is measured for different WL bands.



Sensors could be either non-imaging or imaging sensors.

- Non-imaging sensors measure intensity of radiation, within field of view.
- Imaging sensors give a two-dimensional spatial distribution of emitted/ reflected intensity of EMR (as in a photographic camera)

Two types of imaging sensors

- Non-scanning - entire image is acquired instantaneously - frame by frame
- Scanning type - image is obtained by scanning, pixel by pixel or line by line.

Sensor Parameters

Performance of sensors depends on how accurately objects can be identified/discriminated.

This depends on instrument's ability to detect

- how small objects
- how small difference in reflectance/ emittance
- how many features/objects
- how frequently

Sensor parameters may be considered under four domains - resolutions

- Spatial resolution
- Radiometric resolution
- Spectral resolution
- Temporal resolution

Obtaining a proper combination of these parameters in a sensor is a complex problem due to

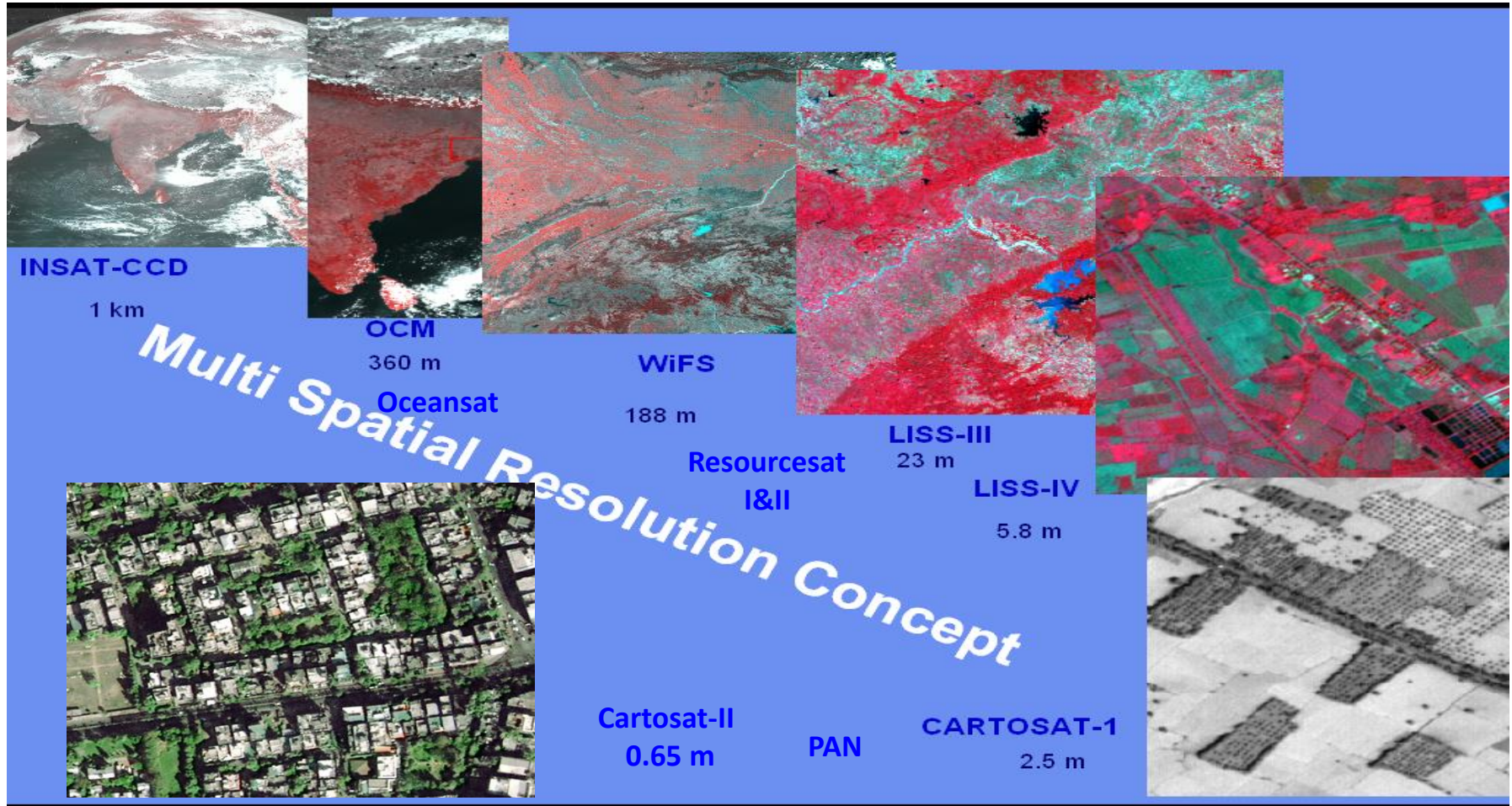
- strong interrelationship between them
- engineering requirements

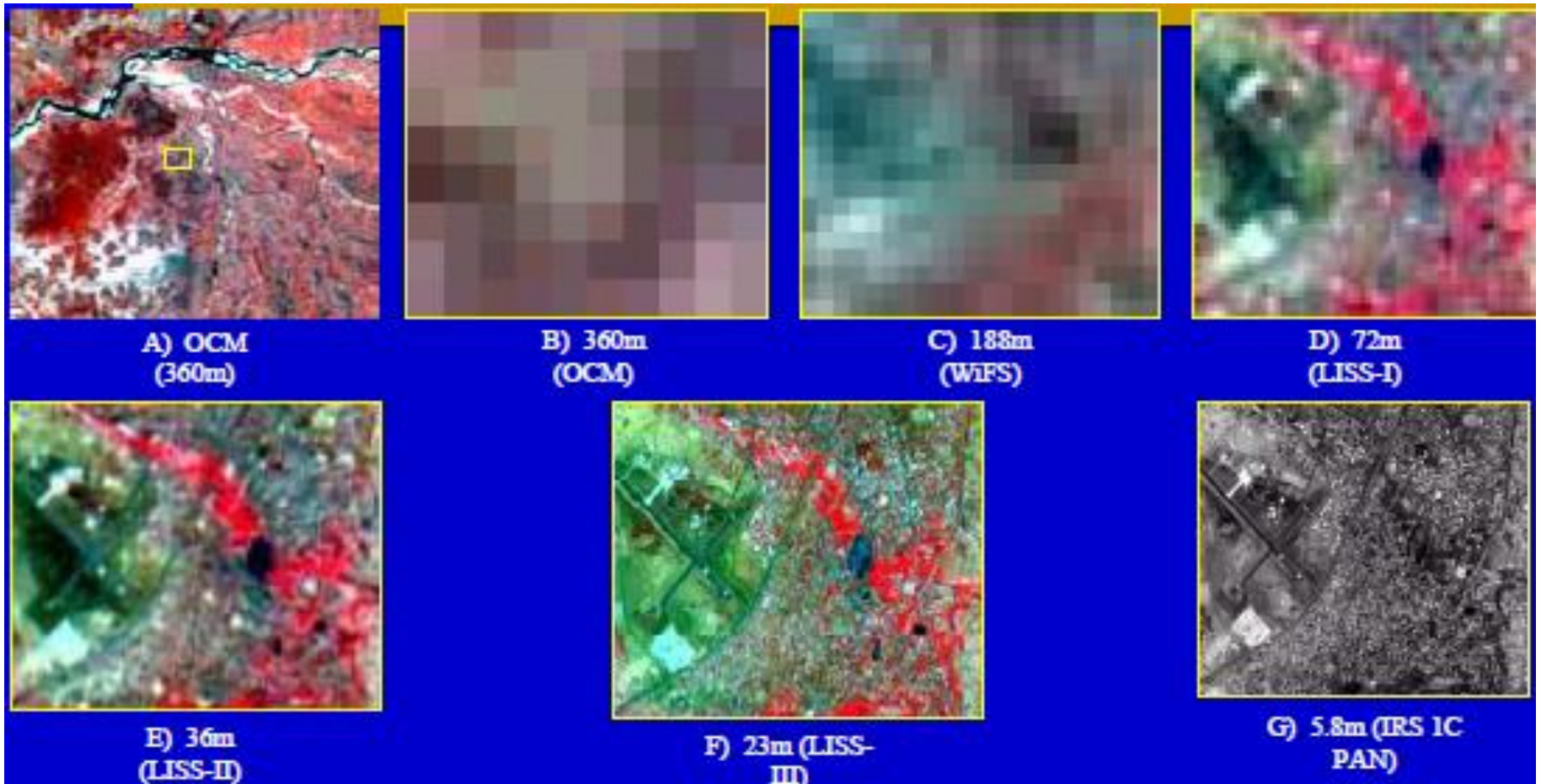
Optimum parameters of a sensor depends on applications.

Spatial Resolution :

Measure of sensor's ability to distinguish/ discriminate closely spaced objects.

A sensor with 1m spatial resolution can reproduce finer details of a scene compared to a sensor with 10m resolution.





Information content Vs resolution.

`A' is from a scene from IRS Ocean Colour Monitor (OCM).

Area in the small square marked ($\approx 4\text{km} \times 4\text{km}$) is shown in various resolutions.

Airport runway is not at all distinguishable at 360 and 188 m resolution.

Details become clearer as resolution improves.

With 5.8m resolution even marking on the runway can be identified.

Theoretical limit of resolving two objects by an imaging system (eg. lens) is set by diffraction of EMR around its aperture.

In absence of any aberration, one expects a perfect lens to image a point object as a point in image plane → this do not happen due to diffraction.

Image of a point object produced by an aberration-free imaging system consist of a bright disc surrounded by concentric dark and bright rings → *airy pattern*.

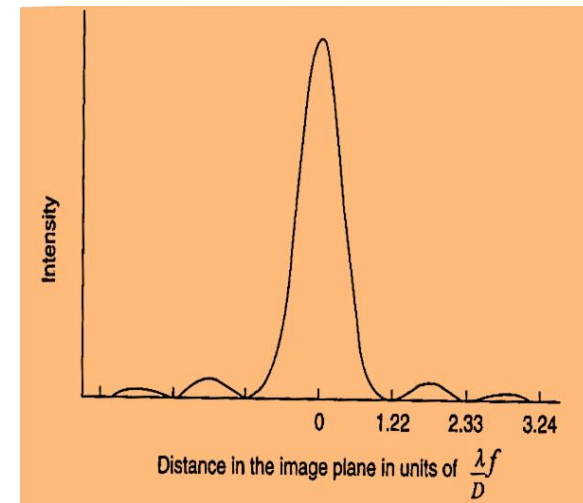
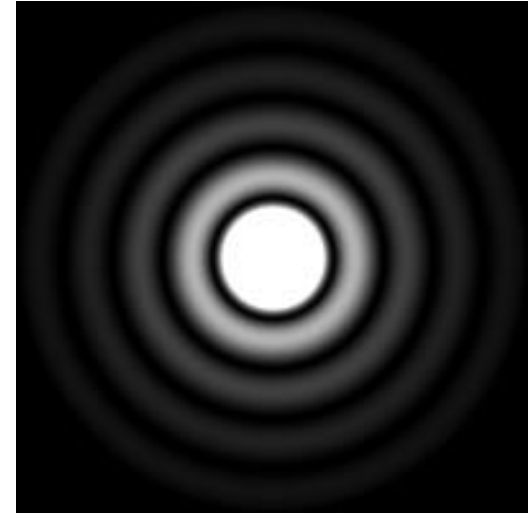
Central disc → *airy disc*.

Distribution of energy in airy pattern due to a circular aperture

Main peak is followed by no. of minima & maxima.

Energy contained between first minima is 84% of total energy.

Diameter of first minima is $2.44 (\lambda/D) f$,
where D - aperture of the lens,
f - focal length and
 λ - WL.



Two objects can be just resolved if peak of airy pattern of one object falls on first minima of other.

Two objects separated by $1.22(\lambda/D)f$ can be just resolved. Objects closer than this cannot be resolved → theoretical resolving limit.

IRS PAN camera,

aperture - 22cm,

wavelength - $0.5\mu\text{m}$

altitude of 810km, spatial resolution limit is

$$1.22 \times (0.5 \times 10^{-6} / 0.22) \times 810 \times 10^3 = 2.25\text{m}$$

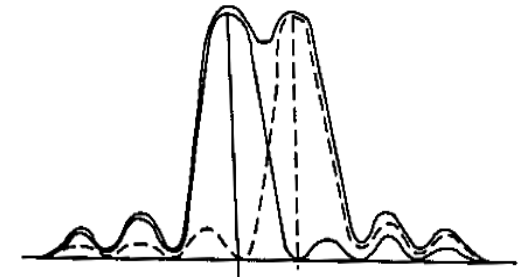
Actual resolution of this instrument was 5.6 m.

Resolution can be improved by reducing WL or by increasing aperture or by reducing focal length.

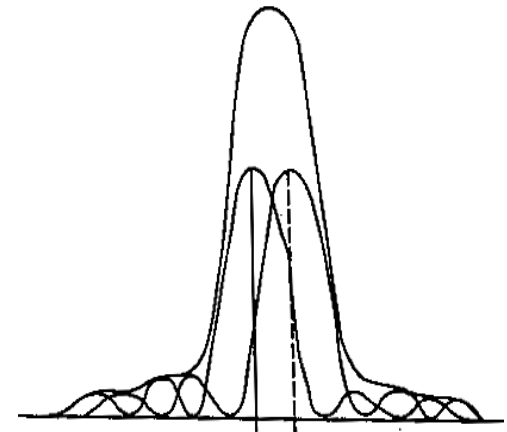
SWIR at $2\mu\text{m}$ → 9 m (poor)

Altitude 710 km → 1.97 m (better)

Aperture 26 cm → 1.97 m (better)



Just resolved



Not resolved

Contrast in image

Difference in radiance of objects in a scene plays an important role in their detection.

Contrast is usually referred w.r.t. two adjacent areas. If $L_{\max}$ and $L_{\min}$ are maximum and minimum radiances between adjacent areas,

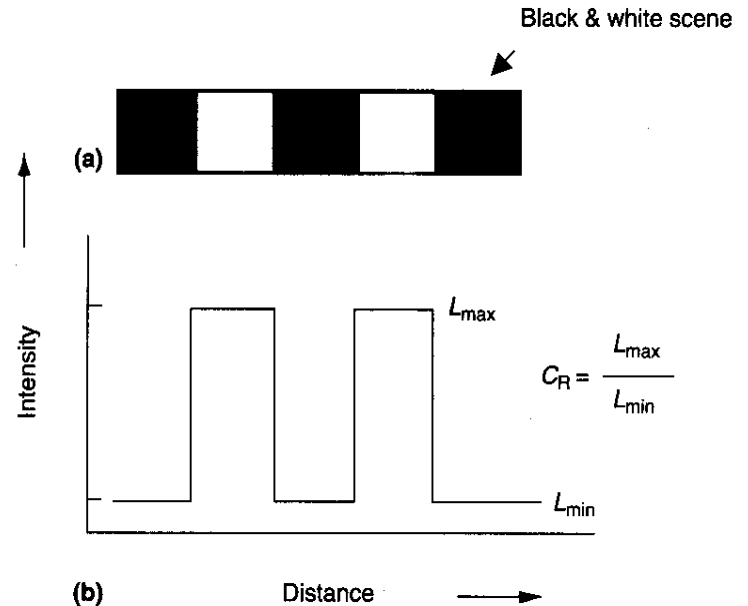
$$\text{Contrast Ratio } CR = \frac{L_{\max}}{L_{\min}}$$

$$\text{Contrast Modulation } CM = \frac{L_{\max} - L_{\min}}{L_{\max} + L_{\min}}$$

Contrast in image will be different from that of scene (object plane). Imaging system reduces contrast. Degradation of contrast by the imaging system is represented by Modulation Transfer Function (MTF)

$$MTF = \frac{CM \text{ in the image plane}}{CM \text{ in the object plane}}$$

Range 0 - 1



Effect of atm scattering on CR

Scattering in atm affect the CR → reduces contrast in image.

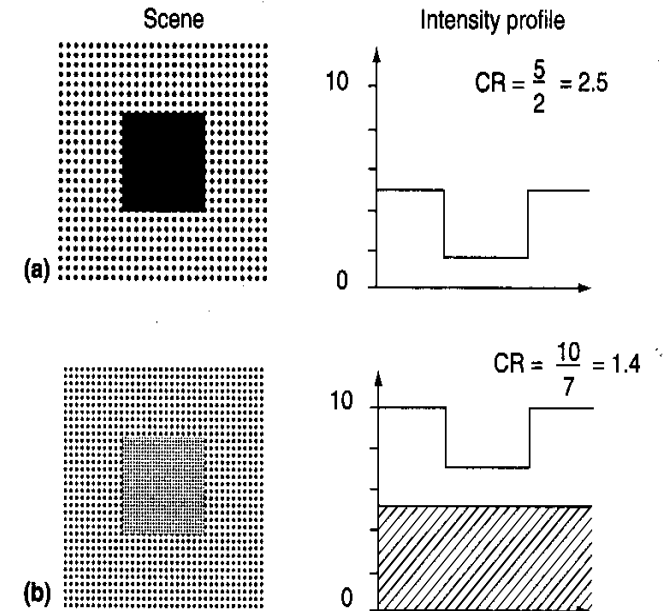
An object resolved in a 'clear' atm, may not be resolved in a hazy atm.

CR is a critical parameter in determining ability to resolve & detect objects.

Other parameters remaining same, objects having high CR can be easily identified than a low CR.

Apart from theoretical limit due to diffraction, the spatial resolution depends on other parameters such as

- object contrast ratio (CR)
- modulation transfer function (MTF)
- signal-to-noise ratio (SNR)



Effect of scattering on CR.

(a) without scattering

(b) with scattering (5 units are added)

GRE, IFOV, FOV

Electronic sensors (like LISS) → spatial resolution is the projection of detector element on ground through optics → Ground Resolution Element (GRE)

Instantaneous Field of View (IFOV) - solid angle through which a detector collects radiation.

Information within an IFOV is represented by a pixel (picture element) in image plane.

Spatial resolution may be represented by size of GRE → pixel size

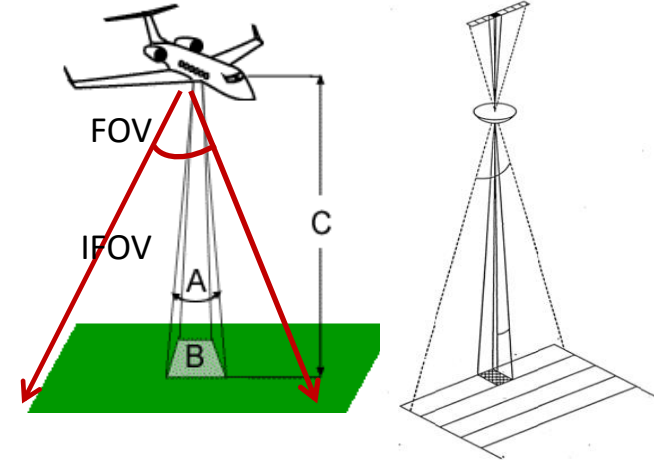
Field of view (FOV) is the total view angle of camera → defines swath.

Landsat

4, 5 TM (Thematic Mapper - 7 bands) - 30 m and 120 m for TIR

7 ETM (Enhanced TM - 8 bands) - 30 m, and 15 m for PAN, 120 m for TIR

8 OLI (Operational Land Imager) & TIR - 11 bands -30m, and 15 m for PAN, 120 m for TIR



Linear Imaging Self Scanning

- LISS-I → 72 m, LISS-II → 36 m, LISS-III → 23 m, LISS-IV → 5.8 m
- WiFS (Wide Field Sensor) → 188 m
AWiFS → 56-70 m
- PAN (Panchromatic) → 2.5 m, 0.65m

MODIS	250-1000m
SPOT	20 m
WorldView 3	1.24 m (PAN 0.3)
Quickbird	0.82 m
ALOS	2.5-100 m
Sentinel 2	10-60 m

Possible to detect objects smaller than GRE in an image.

Eg. roads and railway lines can be identified even in IRS LISS-1 (72 m) or LANDSAT MSS (80 m).

- High contrast with surroundings
- Linear nature of target

What is optimum spatial resolution?

No unique answer → depends on features

If the feature varies slowly in space, high resolution may not be needed
- ocean, desert.

Sea Surface Temp (SST) → poor resolution may be OK

Vegetation → better resolution

Vegetation → poor resolution may be OK

Urban studies → better resolution.

Spatial resolution is important for classification accuracy →

Poor resolution - boundary pixels contribution from both features →
error in classification.

Boundary pixel error can be reduced with improved resolution.

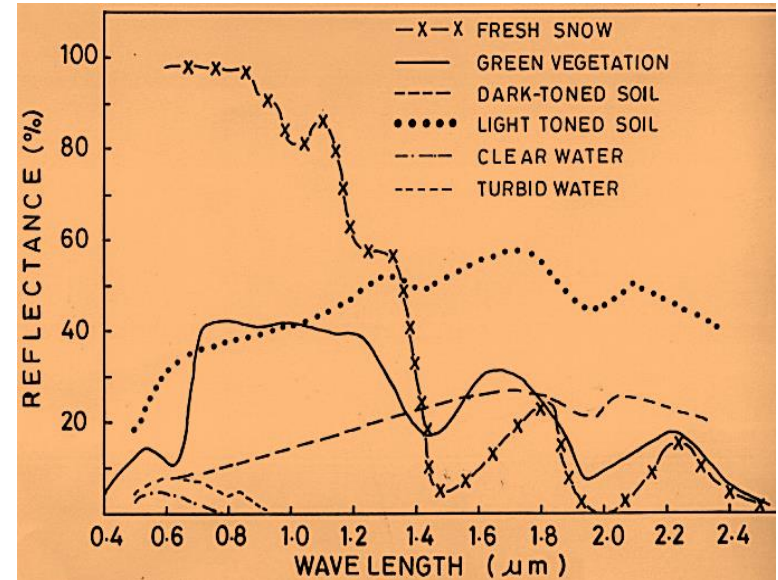
Spectral Resolution :

Difficult to get continuous spectral information → bands

Single band - overlapping

Multispectral imaging → viewing a particular area in few narrow bands to obtain better identification and discrimination (3-12 bands).

Hyperspectral - very narrow bands - hundreds to thousands bands.



BLUE BAND
(0.4-0.5 μm)



1- SAND

GREEN BAND
(0.5-0.6 μm)

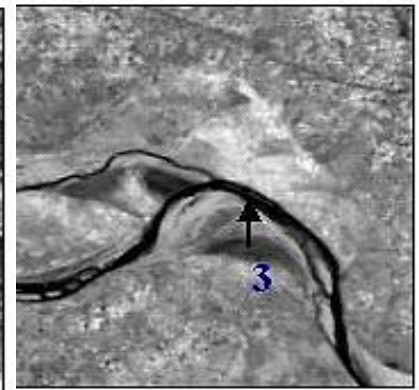


RED BAND
(0.6-0.7 μm)



2-VEGETATION

NEAR IR
(0.7-0.9 μm)



3-WATER

3 aspects in spectral band selection:

- (i) total number of bands**
- (ii) location of central WL**
- (iii) spectral width**

Spectral resolution $\Delta\lambda \rightarrow (\lambda_2 - \lambda_1) \rightarrow$ WL interval in which emittance/ reflectance is collected.

**Narrow spectral bands (Small $\Delta\lambda$) $\rightarrow$ higher (better) spectral resolution
 $\rightarrow$ better discrimination.**

e.g. various rock types $\rightarrow$ narrow spectral band $\rightarrow$ Hyperspectral

Number of spectral bands, central WL and spectral width determine capability to identify/ discriminate individual targets on multispectral image

**Not possible to improve spectral resolution of a sensor beyond a limit, Why?
S/N ratio will decrease.**

Small IFOV (high spatial resolution) $\rightarrow$ poor S/N

Small spectral width (high spectral resolution) $\rightarrow$ poor S/N

Compromise between two requirements $\rightarrow$ high S/N ratio.

How to improve both together $\rightarrow$

Provide longer look at each scene - push broom scanner (e.g. LISS)

Choice of Spectral Bands :

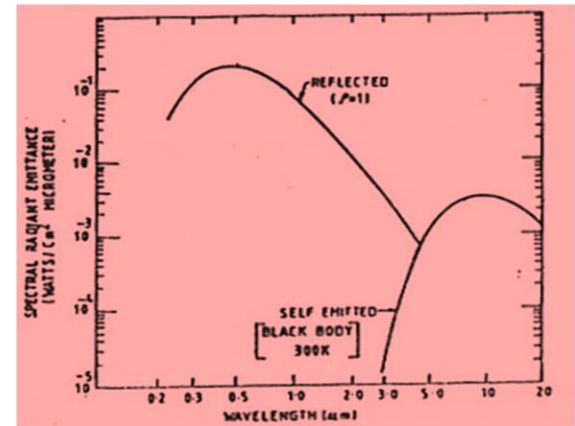
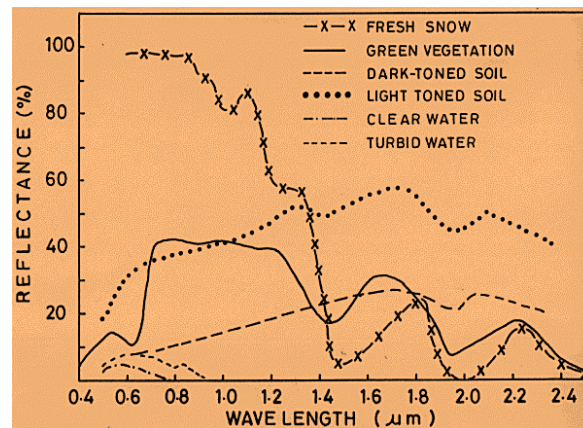
- Based on field spectral signature studies - obtain best suited spectral width for specific themes (high discrimination power)
→ LANDSAT - Thematic Mapper (TM) bands
- Should be in the atm window
- Bands should be un-correlated → correlated bands give redundant information → does not help to improve discriminability.

Since data rate increases directly with no. of bands, selection of optimum number of bands is important.

Landsat-4 & 5 TM (Thematic Mapper) bands

TM 7 Bands

1-Blue	0.45 - 0.52 μ
2-Green	0.52 - 0.60
3-Red	0.63 - 0.69
4-N IR	0.76 - 0.90
5-SW IR	1.55 - 1.75
7-SW IR	2.08 - 2.35
6-TIR	10.4 - 12.5



Spatial res. 30 m & 120 in TIR
Note the width of bands

Landsat-7 ETM - 8 bands

B8 - PAN 0.52 - 0.9 μ

Landsat-8 OLI & TIRS, Total 11 bands

Landsat-4&5 TM bands and their applications List is only indicative not complete

TM Bands		
Bands	WL (μm)	Application
TM 1	0.45 - 0.52 (blue)	Sensitivity to chlorophyll - soil/vegetation discrimination, forest type mapping, coastal mapping, urban feature identification
TM 2	0.52 - 0.60 (green)	Green reflectance - vegetation discrimination and vigour assessment
TM 3	0.63 - 0.69 (red)	Sensitivity to chlorophyll - plant species identification; water type discrimination
TM 4	0.76 - 0.90 (NIR)	Vegetation type, vigour, biomass determination; water body delineation
TM 5	1.55 - 1.75 (SWIR-1)	Sensitive to moisture in soil - drought studies, snow/cloud differentiation
TM 6	10.4 - 12.5 (TIR)	Vegetation stress and soil moisture discrimination, temperature
TM 7	2.08 - 2.35 (SWIR-2)	Discrimination of mineral and rock types, sensitive to vegetation moisture content

Radiometric Resolution :

In electro-optical sensors, output is usually digitized or quantized to produce discrete levels, and is expressed as bits.

- 7-bit digitization $\rightarrow 2^7$ or 128 discrete levels (0-127).
- 8-bit digitization $\rightarrow 2^8$ or 256 discrete levels (0-255).
- 10-bit digitization $\rightarrow 2^{10}$ or 1024 discrete levels (0-1023).
- 12-bit digitization $\rightarrow 2^{12}$ or 4096 discrete levels (0-4095).

An image with 1024 levels will have better capability for extraction of information compared with an image with 256 levels.

Radiometric Resolution is the capability to differentiate smallest changes in spectral reflectance /emittance between various targets.

Radiometric Resolution depends on quantization levels within the spectral band.

More the no. of bits, better the radiometric resolution

Saturation radiance

Sensor with 8 bit resolution - saturation set at 100%

Sensor with 7 bit resolution - saturation set at 25%



Radiometric quality

Radiometric quality of an image depends on

- **Spatial resolution**
- **contrast in the image**
- **radiance saturation value**
- **atmospheric effect - path radiance reduces the contrast and also adds to actual reflectance value**
- **modulation transfer function (MTF) - contrast reduction from object plane to image plane**
- **radiometric resolution**
- **calibration accuracy**

Temporal Resolution (Repetivity)

One of the main advantages of satellite RS - ability to repeatedly observe same scene at regular intervals.

Temporal resolution refers to the time interval between two observations of same area - usually expressed in days.

Temporal resolution depends on

- orbit characteristics
- swath.

Higher the height → better temporal resolution

Highest temporal resolution → Geo sat like INSAT, METEOSAT etc.,
→ about 30 minutes.

Larger the swath → better the temporal resolution.

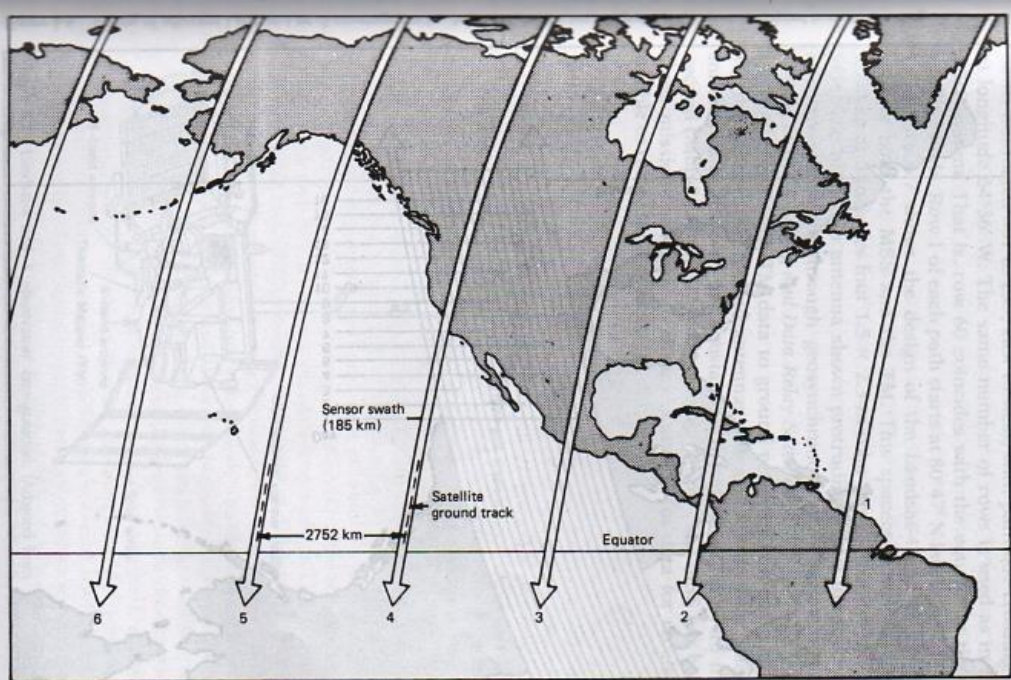
SeaWiFS swath - 3000 km → high temporal resolution - one day.

Cartosat II swath - 9.6 km → poor temporal resolution - 310 days

- Resourcesat AWiFS → 5 days

LISS III → 24 days, LISS IV → 5 days

- Cartosat I PAN → 126 days Cartosat II PAN → 310 days



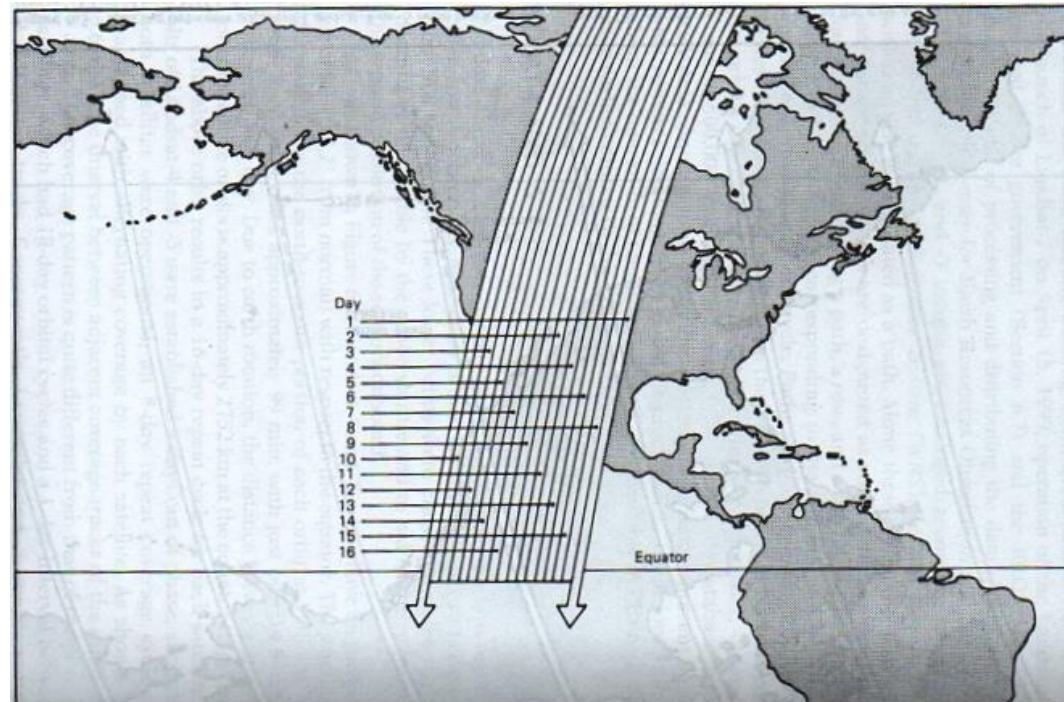
Landsat 4-8

Height - 705 km

Repetivity - 16 days

Swath - 185 km

Between - 2752 km

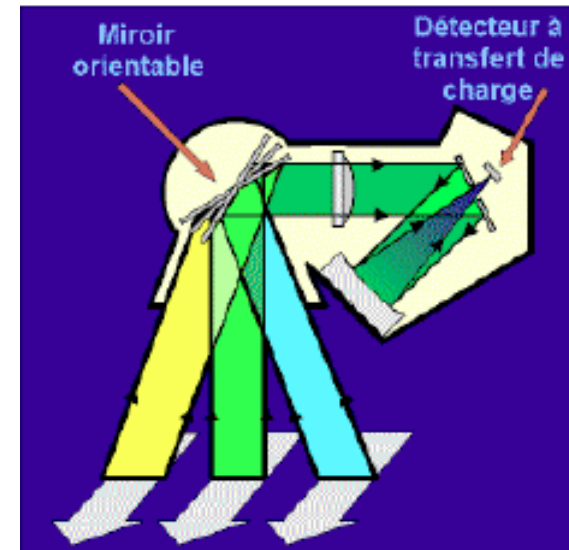


Advantages of higher temporal resolution

- Helps to monitor features which changes rapidly - forest fire, floods, cyclones etc.
- Improves probability of obtaining cloud-free imagery
- Helps to identify features based on temporal signature

Revisit capability

- Capability of imaging an area by tilting view direction of camera across-track – SPOT
- Increases frequency of observation of a specific site.
- Helps to image specific area at shorter intervals than temporal resolution of 26 days of SPOT.



Revisit capability & temporal resolution.

Revisit of a location is carried out at the cost of not acquiring data over some other location → will not get global coverage.

Factors affecting signal strength (S/N)

- Intensity of radiation - time of the day and season, haziness of atm
- Height of sensor - higher the position, less intense
- Spatial resolution - IFOV
- Spectral resolution - spectral width
- Dwell time - similar to shutter speed

Trade-off between four resolutions

To get high spatial resolution, IFOV has to be reduced → reduces the energy collected by sensor → poor S/N → poor radiometric quality.

With high spatial resolution, radiometric quality can be improved by increasing spectral width (collecting more energy) → reduces spectral resolution.

High spatial resolution, high spectral resolution and high radiometric quality
→ increase dwell time

Higher spatial resolution and large swath results in increased data size.

Judicial choice of sensor parameters.

Satellite system parameters relevant to RS

➤ Instrumental parameters

■ Sensor parameters

- Spectral bands - no. of bands, central WL, spectral resolution
 - visible/(reflective IR 0.4 - 3 μ)
 - TIR (emissive 8 - 14 μ)
 - Microwaves (backscattered 1 mm - 1m)
- IFOV - GRE - spatial resolution
- FOV - swath - temporal resolution
- No. of bits - digitization of detector output - radiometric resolution
- MTF - change in contrast - radiometric quality
- Polarization (Radar) - vertical/horizontal/circular (transmit/receive)
 - backscattering properties of target are different for V and H

■ Viewing angle → Nadir - vertically down → less distortion

■ Data handling capability - Transmitter, receiver, antenna etc

➤ Orbital Parameters

Height → swath, spatial resolution, temporal resolution

Geo - poor spatial resolution - larger swath - high temporal resolution

Swath → maximum swath is limited by its data transmitting speed

- High spatial resolution systems, swath will be limited
- Scanners with 15-20m resolution → swath is about 100 km
- Scanners with 1 km or more spatial resolution → > 1000 km

e.g.,
INSAT,
EUMETSAT ,
GOES (US),
MSAT (Japan)

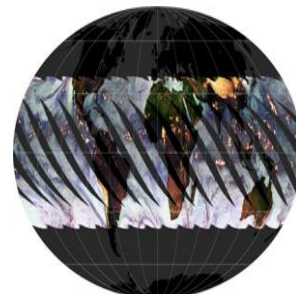
		sp res	swath	temp res
Resourcesat-II	AWiFS	56 m	740 km	5 days
	LISS-III	23 m	140 km	24 days
	LISS-IV	5.8 m	70 km	5 days (revisit)
Cartosat-II	PAN	0.65 m	9.6 km	310 days

e.g.
Resourcesat,
Cartosat,
LANDSAT,
MODIS

Inclination - latitudinal coverage

- equatorial
- polar - global coverage
- near polar - Sun synchronous → adjusting height & inclination → similar illumination - very important for VIS/IR RS.
- inclined - equal time in NH & SH
 - low inclination → only over tropical region
 - better temporal resolution

Orbit choice - compromise → resolutions, swath, inter-orbit space etc



TRMM 35°

Sensors

➤ Non-imaging

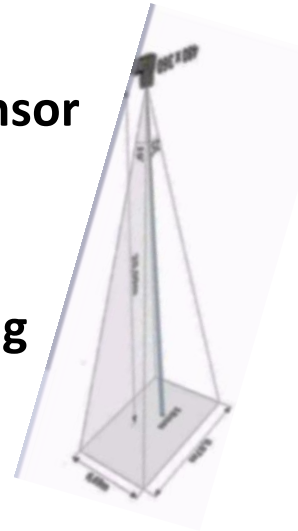
Do not form image, record spectral quantity as a function of time

➤ Imaging

- **Non-scanning (Frame by frame)/ (Staring mode)** - snapshot - at one instant covering entire area of surface depending on sensor characteristics and platform height

Camera - Photographic, digital

Disadvantage - Distortion at the edges due to large lens opening



- **Scanning**

Opto-mechanical scanners

- Distortions are minimised and resolution is improved by using narrow beam of light → achieved by scanning systems.
 - Pixel by pixel (whiskbroom)/ (across the track)

Electro-optical scanners

- With electronic detectors, scanners can
 - extend spectral range to IR and microwaves
 - can sense in very narrow bands.
 - Line by line (pushbroom)/ (along the track)

Pixel by Pixel/ Across-track/ Whiskbroom scanning

Radiation from ground will be intercepted by scan mirror.

Detector receives radiation from one GRE defined by detector size and focal length

At any instant, scanner receives energy from only one pixel
→ pixel by pixel.

By rotating scan mirror ($\approx 45^\circ$) detector looks at adjacent pixels at right angles to direction of platform → across track

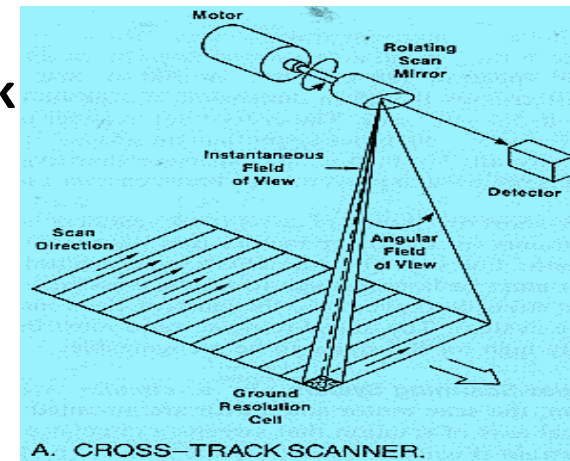
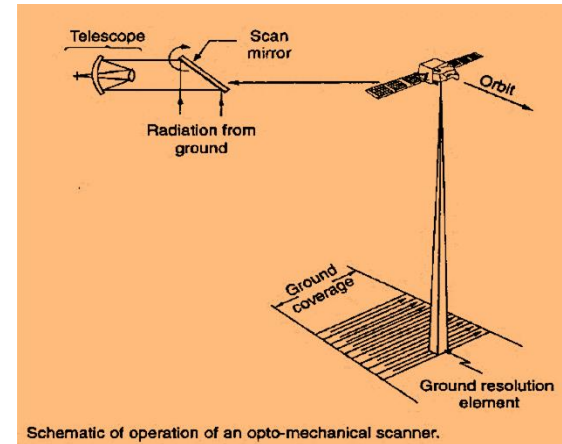
Repeatedly measures energy from one side to other.

Successive scanlines are covered as spacecraft moves forward → series of narrow strips → a two-dimensional image of rows (scan lines) and columns e.g. INSAT

Scan frequency has to be adjusted depending on velocity of platform and pixel dimension to produce continuous image.

To produce multispectral image, energy collected by telescope is passed through a dispersing system.

Practical limit in improving spatial resolution using opto-mechanical scanners



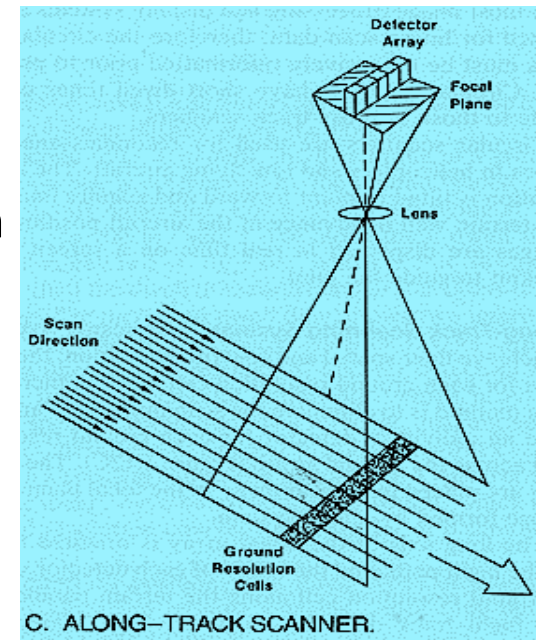
Along-track/pushbroom scanning – electro-optical

Linear array of detectors instead of rotating mirror → CCD

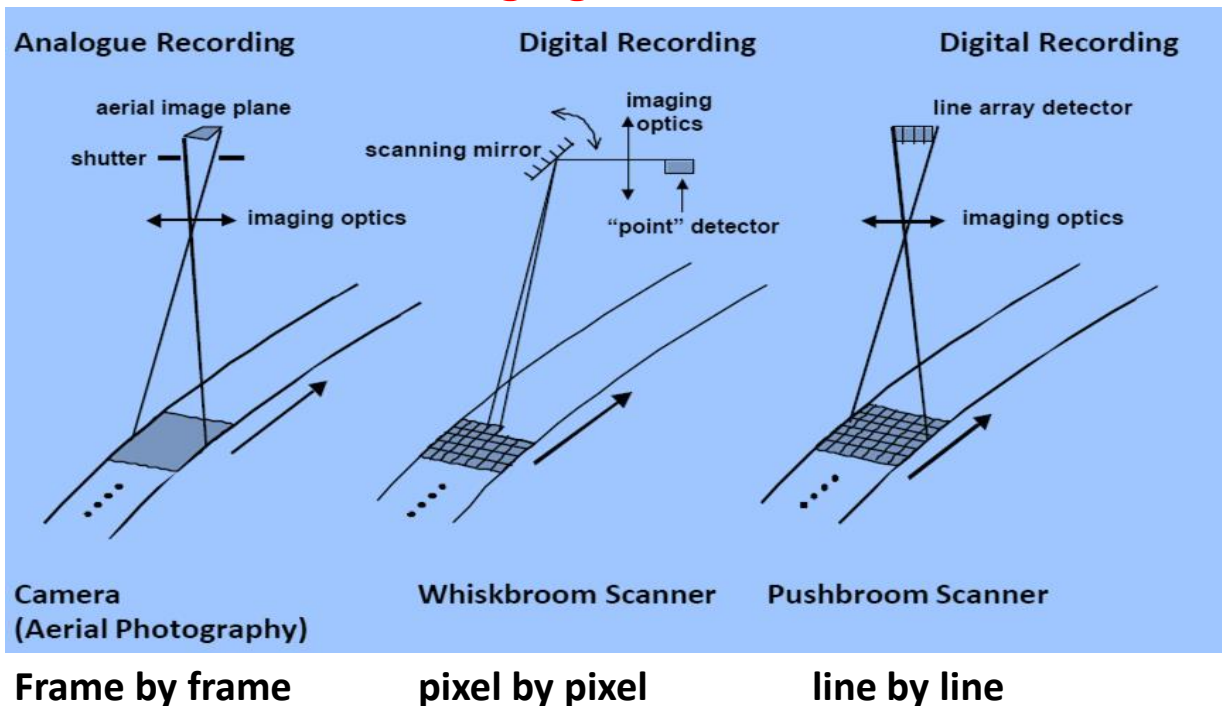
Optics focuses a strip of terrain in the across track direction of sensor array - scanline.

As spacecraft advances forward, it scans earth over swath → two dimensional image.

Scanners record multiband image data along a swath.
e.g. LISS



Imaging Methods



Sensors

➤ Optical –

- Vis, NIR, SWIR

 - eg. IRS, Resourcesat, Cartosat-LISS, WiFS, PAN

- TIR

- Optical and Thermal

 - eg. Landsat - TM

 - (Vis, NIR, SWR, TIR)

 - INSAT - VHRR

 - (VIS, MIR (water vapour channel), TIR)

➤ Microwave

- eg. Active - Radars –

 - SeaSat, ERS, RadarSat, JERS, RISAT

- Passive - Radiometer - MSMR

Optical remote sensors

- Panchromatic - single channel with broad WL - appears B&W photograph

 - eg. SPOT PAN (0.45-0.745),
Landsat ETM PAN (0.52-0.0),
Cartosat PAN (0.45 - 0.85)

- Multispectral

 - eg. Landsat-8 & 9 11 bands
Sentinel 2A & 2B - ESA 13 bands
Resourcesat LISS-IV 3 bands
LISS-III 4 bands

- Hyperspectral

 - eg. Hyperion NASA - 242 channel
HySIS India - 316 ch, 10 nm, 2018
Proba ESA

Satellites based on application

- Earth resource satellites

- Meteorological satellites

- Oceanographic satellites

- Astronomical satellites

Landsat Satellite Program

National Aeronautics and Space Administration (NASA), USA

First satellite designed to acquire data about earth resources on a systematic, repetitive, medium resolution, multispectral basis.

**Initially - Earth Resources Technology Satellites (ERTS) - renamed as Landsat
ERTS-1 → Landsat-1 – 1972**

Currently orbiting - Landsat 8 (2013) and Landsat 9 (2021)

Large no of applications - agriculture, forestry, cartography, civil engineering, environmental monitoring, geography, geology, land resources analysis, Land-use planning, oceanography, water quality analysis etc.

Table 4.1 Characteristics of Landsat Satellites and Their Sensors

Satellite Capabilities :

Particulars	Landsat - 1 to 3	Landsat - 4 & 5
Altitude	919 Km	705 Km
Orbit	Near-Polar Sun-Synchronous	Near-Polar Sun-Synchronous
Inclination	99.09 Degree	98.2 Degrees
Period	103 minutes	99 minutes
Equatorial crossing time	0930 Hours	0945 Hours
Repeat Cycle	18 Days	16 Days
Swath Width	185 Km	185 Km
Data rate	15.06 Mbps	84.9 Mbps

Sensor Capabilities :

Sensor	Mission	Channel	Spectral Spatial Resolution (Microns)	Spatial Resolution	Radiometric Resolution
RBV	Landsat 1 to 3	1	0.475-0.575	80 m	6 bits (127 levels)
		2	0.580-0.680	80 m	
		3	0.690-0.830	80 m	
		4	0.505-0.750	80 m	
MSS	Landsat 1 to 5	1	0.5-0.6	79/82 m*	6 bits (127 levels)
		2	0.6-0.7	79/82 m*	
		3	0.7-0.8	79/82 m*	
		4	0.8-1.1	79/82 m*	
		5	10.4-12.6	240 m	
TM	Landsat 4 & 5	1	0.45-0.52	30 m	8 bits (255 levels)
		2	0.52-0.60	30 m	
		3	0.63-0.69	30 m	
		4	0.76-0.90	30 m	
		5	1.55-1.75	30 m	
		6	2.08-2.35	30 m	
		7	10.4-12.5	120 m	

* The Spatial Resolution is 79 m for Landsat-1, 2 & 3. It is 82 m for Landsat 4 & 5.



Landsat 7



Landsat 7 Enhanced Thematic Mapper Plus (ETM+)	Bands	Wavelength (micrometers)	Resolution (meters)
	Band 1 - Blue	0.45-0.52	30
	Band 2 - Green	0.52-0.60	30
	Band 3 - Red	0.63-0.69	30
	Band 4 - Near Infrared (NIR)	0.77-0.90	30
	Band 5 - Shortwave Infrared (SWIR) 1	1.55-1.75	30
	Band 6 - Thermal	10.40-12.50	60 * (30)
	Band 7 - Shortwave Infrared (SWIR) 2	2.09-2.35	30
	Band 8 - Panchromatic	.52-.90	15

* ETM+ Band 6 is acquired at 60-meter resolution, but products are resampled to 30-meter pixels.

New band - PAN - high spatial resolution - broad spectral width
Improved resolution

Landsat 8 (2013)

- Operational Land Imager (OLI) 1-9 bands
- Thermal Infrared Sensor (TIRS) 10-11 bands



Sun synchronous - 705 km

Inclination - 98.22

Speed in orbit - 7.5 km/s

Period - 98.8 min

Repetivity - 16 days

Ultra blue Band 1 → coastal and aerosol studies.

Band 8 → PAN - 15 m.
Reduced spectral width

Band 9 → cirrus cloud detection.

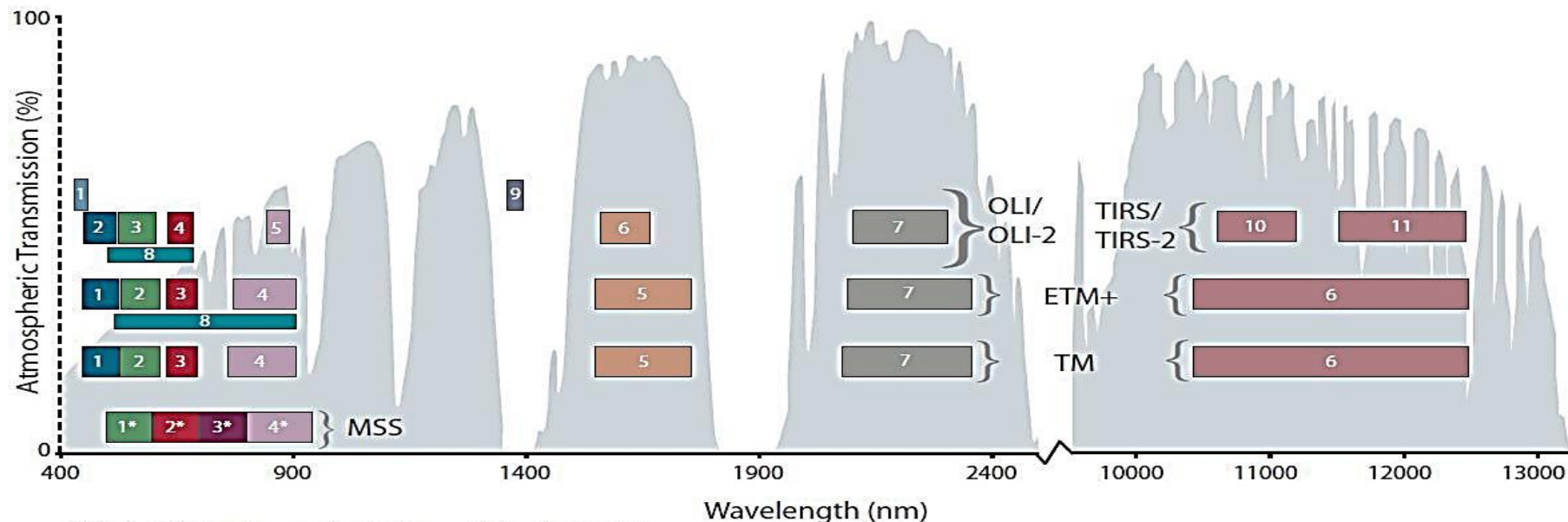
TIR 10 and 11 → accurate surface temp.

More precise spectral width

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)	Bands	Wavelength (micrometers)	Resolution (meters)
	Band 1 - Ultra Blue (coastal/aerosol)	0.435 - 0.451	30
	Band 2 - Blue	0.452 - 0.512	30
	Band 3 - Green	0.533 - 0.590	30
	Band 4 - Red	0.636 - 0.673	30
	Band 5 - Near Infrared (NIR)	0.851 - 0.879	30
	Band 6 - Shortwave Infrared (SWIR) 1	1.566 - 1.651	30
	Band 7 - Shortwave Infrared (SWIR) 2	2.107 - 2.294	30
	Band 8 - Panchromatic	0.503 - 0.676	15
	Band 9 - Cirrus	1.363 - 1.384	30
	Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19	100 * (30)
	Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100 * (30)

TIRS bands - acquired at 100 m resolution, resampled to 30 m to match with resolution of other sensors.

Landsat Bands



* MSS bands 1-4 were known as bands 4-7, respectively, on Landsats 1-3

Landsat 1-5 **MSS 4 bands +
TM 7 bands**

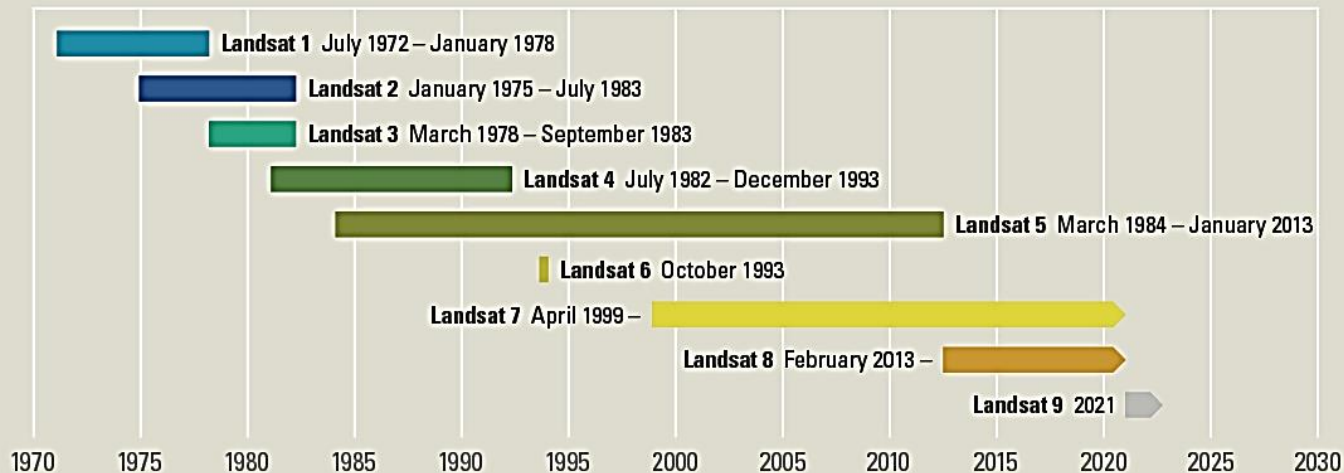
Landsat 7 **ETM 8 bands**

Landsat 8 **OLI + TIRS 11 bands**

Location of bands in the spectrum - window region

Band 9 in OLI - cirrus band - absorption region

Landsat Missions: Imaging the Earth Since 1972



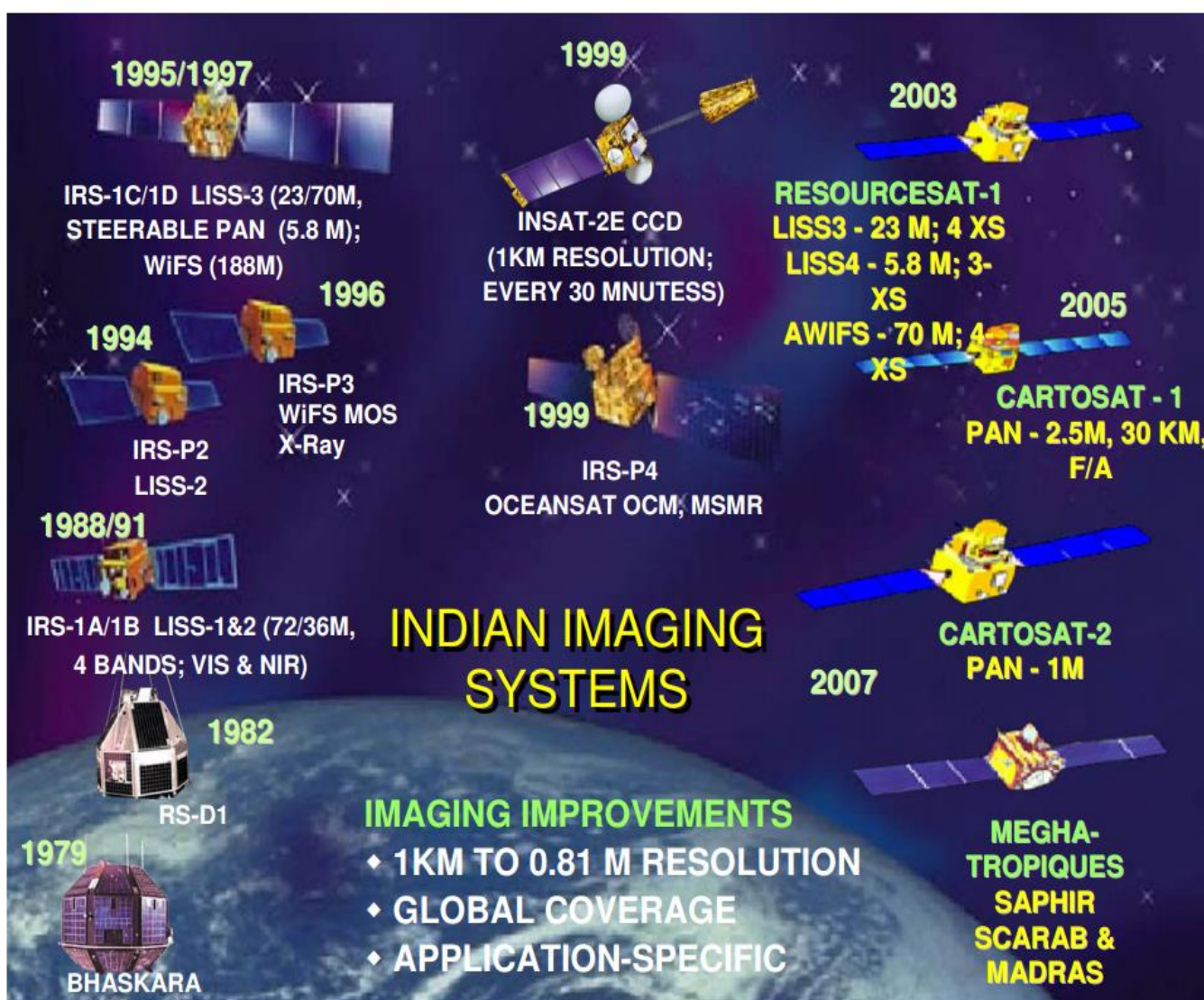
Landsat provides longest continuity of space-based moderate-resolution land remote sensing data

Landsat 9 sensor is very similar to Landsat 8 → 11 bands

Landsat 7 - 8 bit - 256 levels

Landsat 8 - 12 bit - 4096 levels

Landsat 9 - 14 bit - 16,384 levels



Aryabhata (1975), Edusat (2003), Astrosat (2015), XPoSat (2024), INSAT, GSAT, IRNSS, Chandrayan, Aditya

Currently available Indian RS satellites (Jan 24)

C2A-F, C3, O2, R2, R2A, Saral, Scatsat, HySIS, Risat 2B, 2BR1, EOS 1,4,6,7 INSAT (to be verified)

Cartosat 2A 2008

Risat-2 2009

Oceansat-II 2009

Cartosat 2B 2010

Resourcesat-2 2011

Meghatropiques – 2011

Risat-1 2012 -Indigenous

Saral 2013 (Ocean...)

Resourcesat 2A 2016

SCATSAT-1 Sept,16

Cartosat 2D Feb 17

Cartosat 2E June 17

Cartosat 2F Jan 18

HySIS Nov 18

Risat 2B May 19

Cartosat 3 Nov 2019

Risat 2BR1 Dec 19

EOS-I (Risat 2bR2) Nov 20

EOS-4 Feb 22

EOS-6 Nov 22

EOS-7 Feb 23

Indian Remote Sensing (IRS) 1988

First Generation

IRS 1A/1B - 2 sensors LISS-1 (72m) & LISS-2 (36)

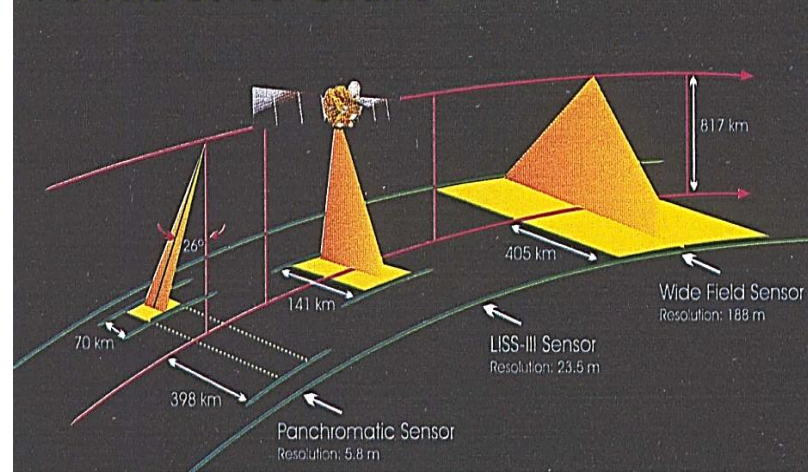
Linear Imaging Self-scanning Sensor (4 bands)

Second Generation

IRS-1C/1D - three sensors:

- 4-channel medium res (LISS-III) – 23.5 m,
- Single-ch high res panchromatic (PAN) 5.8 m
- 2-ch - coarse res Wide Field Sensor (WiFS) 188 m

IRS-1C/D Sensor Swaths



Sensor	Wavelength Range (μm)	Spatial Resolution	Swath Width	Repetivity (at equator)	Quantization (bits)
LISS-III			141 km	24 days	7
Green	B2 - 0.52 - 0.59	23 m			
Red	B3 - 0.62 - 0.68	23 m			
Near IR	B4 - 0.77 - 0.86	23 m			
Shortwave IR	B5 - 1.55 - 1.70	70.5 m			
WiFS		188 m	~800 km	5 days	7
Red	B3 - 0.62 - 0.68				
Near IR	B4 - 0.77 - 0.86				
PAN	0.5 - 0.75	5.8 m	70 km	24 days	6

Third Generation - Resourcesat and Cartosat

Resourcesat I

Orbit :	Circular Polar Sun Synchronous
Orbit height :	821 km
Orbit inclination :	98.76°
Orbit period :	101.35 min
Number of Orbits per day :	14
Local Time of Equator crossing :	10.30 a.m.
Repetivity (LISS-3) :	24 days (341 orbits)
Revisit (AWiFS) :	5 days
Lift-off Mass :	1,360 kg
Attitude and Orbit Control :	3-axis body stabilized using Reaction Wheels, Magnetic Torquers and Hydrazine Thrusters
Power :	Solar Array generating 1250 W (at EOL), Two 24 Ah Ni-Cd batteries
Mission Life :	5-7 years

PAYLOADS	LISS-4	LISS-3	AWiFS
Spatial Resolution (m)	5.8	23.5	56
Swath (km)	23.9 (MX mode) 70.3 (PAN mode)	141	740
Spectral Bands (micron)	0.52-0.59 0.62-0.68 0.77-0.86	0.52-0.59 0.62-0.68 0.77-0.86 1.55-1.70	0.52-0.59 0.62-0.68 0.77-0.86 1.55-1.70
Quantisation (bits)	7	7	10



Resourcesat-1
(IRS-P6)

Comparison with IRS IC/ID

- LISS-III same with 4 bands
- New LISS-IV with 3 bands
- Improved AWiFS
 - Sp. Res 188m → 56 m
 - Bands 2 (R,IR) → 4 (G,R,NIR,SWIR)
 - Quantization 7 → 10
- Removed PAN

All sensors - Pushbroom mode with linear array of CCD

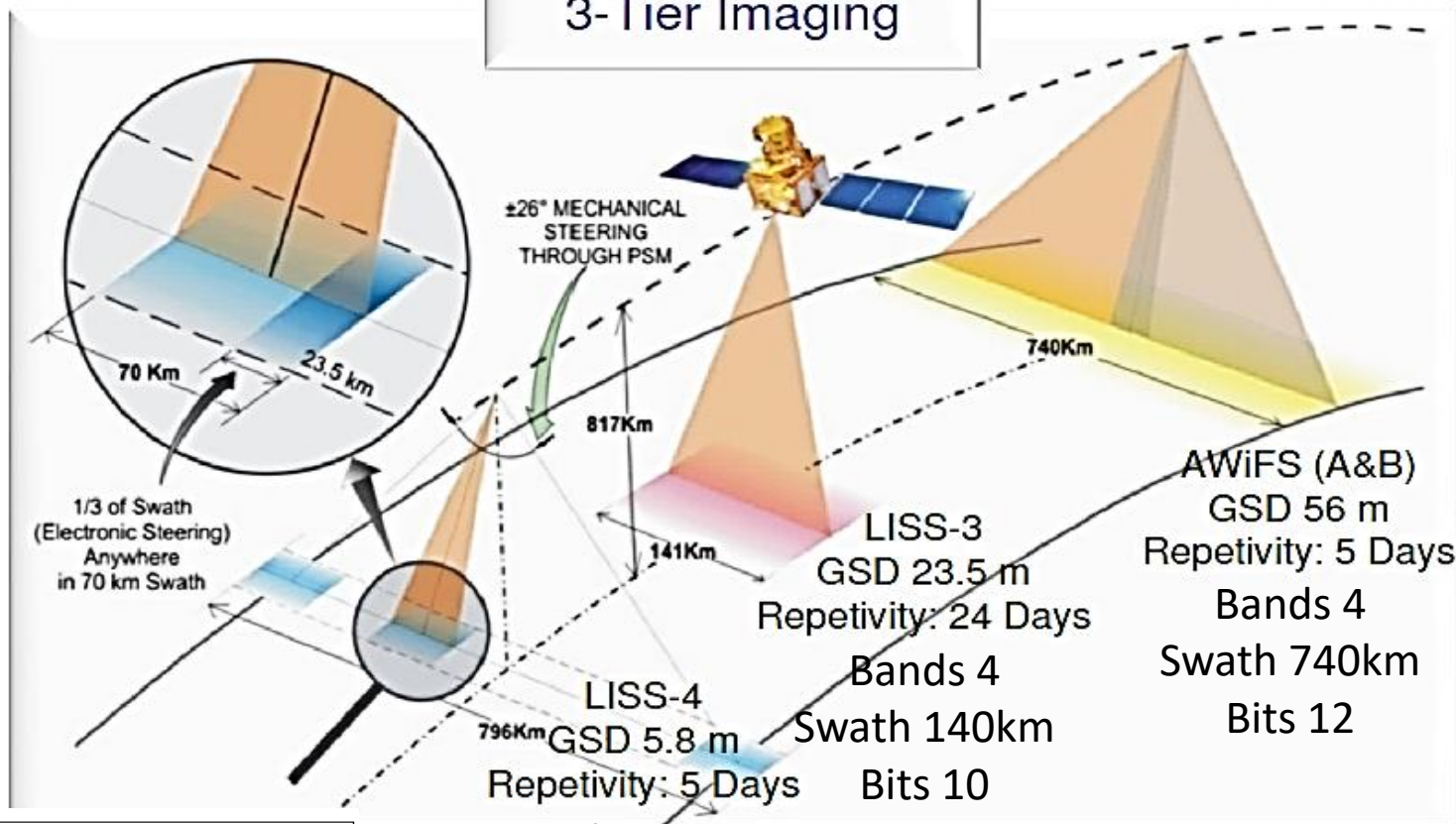
RESOURCESAT- II

SPECIFICATIONS	AWiFS	LISS-III	LISS-IV
No. of Bands	4	4	1 (mono), 3 (MX)
Spectral Bands (μ)	B2 0.52 – 0.59 B3 0.62 – 0.68 B4 0.77 – 0.86 B5 1.55 – 1.70	B2 0.52 – 0.59 B3 0.62 – 0.68 B4 0.77 – 0.86 B5 1.55 – 1.70	B2 0.52 – 0.59 B3 0.62 – 0.68 B4 0.77 – 0.86 B3-default band for mono
Resolution (m)	56	23.5	5.8
Swath (Km)	740	140	70 / 23
Revisit (days)	5	24	5
Data Rate (Mbs per stream)	105	105	105
Quantisation	12-bit	10-bit	10-bit

Improved quantization compared to Resourcesat I
 LISS III & IV (7 $\rightarrow$ 10) AWiFS (10 $\rightarrow$ 12)

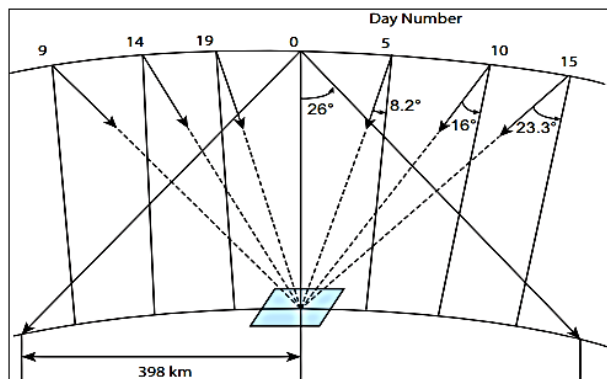
RESOURCESAT-2

3-Tier Imaging



Bands 3
Swath 70km
Bits 10

GSD – Ground Sampling Distance
(spatial resolution)



RESOURCESAT-II

AWiFS



Part of Krishna Basin

Acquired on 04-05-2011



LISS-III

Acquired on 02-05-2011



LISS-IV

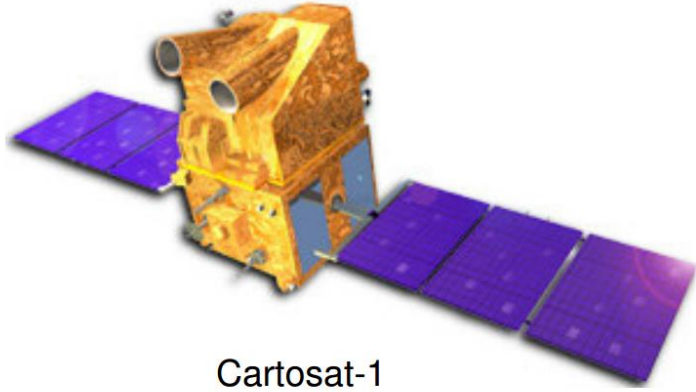


Part of Dubai

Acquired on 08-05-20



Cartosat I



Cartosat-1
(IRS-P5)

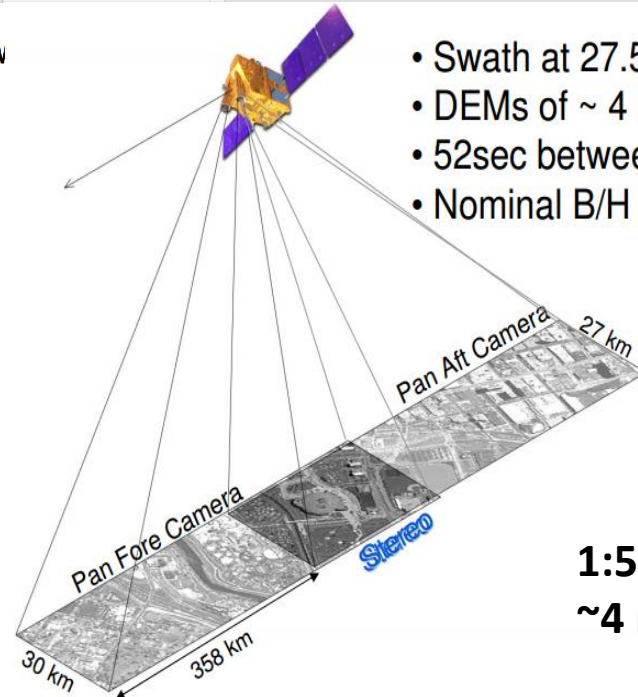
Orbit :	Circular Polar Sun Synchronous
Orbit height :	~618 km
Orbit inclination :	98.87°
Orbit period :	97 min
Number of Orbits per day :	15
Local Time of Equator crossing :	10.30 a.m.
Orbital Repetivity Cycle :	126 days
Nominal Wait Time to Acquire Adjacent Path :	11 days
Max. Wait Time for Revisit :	5 days
Data Rate :	105 Mb/s
Solid state storage:	120GB
Lift-off Mass :	1,560 kg
Attitude and Orbit Control :	3-axis body stabilized using Reaction Wheels, Magnetic Torquers and Hydrazine Thrusters
Power :	5 sq m Solar Array generating 1100W (End Of Life) Two 24 Ah Ni-Cd batteries
Mission Life :	5 – 7 years (launched 05/05/05)

19

- Cartosat-1 has two (2) panchromatic cameras for in flight stereo view
- Stereo data is provide to ground stations in *Real-Time*

Sensor	PAN Fore	PAN Aft
Tilt Along Track	+26°	-5°
Spatial Resolution	2.5 m	2.5 m
Swath-width	30 km	27 km
Radiometric Resolution, Quantisation	10 bit	10 bit
Spectral coverage	500-850 nm	500-850 nm
CCD arrays (number of arrays * No. of elements)	1 * 12000	1 * 12000

- Revisit capability is 5 days (by rolling on axis $\pm 23^\circ$)



- Swath at 27.5 km
- DEMs of ~ 4 m elevation accuracy
- 52sec between cameras ~ 358 km
- Nominal B/H ratio 0.62

1:5000 map
~4 m contour

CAERTOSAT-2

Cartosat-II



CARTOSAT-2 Spacecraft with its solar panels in stowed condition

Altitude	: 630 km
Inclination	: 97.91 deg
Period	: 97.4 min
Local time at descending node	: 9.30 am
Orbits/day	: 14
Revisit	: 4 days
Repetivity	: 310 days
Lift-off Mass	: 680 kg
Attitude and Orbit Control	: 3-axis body stabilised using high torque Reaction Wheels, Magnetic Torquers and Hydrazine Thrusters
Power	: Solar Array Generating 900 W, Two 18 Ah Ni-Cd batteries
Payload	: Panchromatic camera (PAN)
Operational Life	: 5 years
PAN specifications	
Resolution	: Better than one metre
Swath	: About 9.6 km
Spectral Band	: 0.5 – 0.85 micrometre
Data rate	: 336 MBPS
Solid State Recorder	: 64 GB capacity for imagedata storage

Only one PAN, Steer along the track and across the track 45 °
Revisit 4 days, can be improved to 1 day by suitable orbit adjustment

Cartosat-II Bangalore



Cartosat 3 9th satellite in Cartosat series

Launch 27th Nov., 2019

Altitude 509 km

Inclination 97.5

Life period 5 years

Details are not fully available

Resolution < 40 cm (not sure) -
allows head-count in traffic junctions

HySIS – HyperSpectral Imaging Satellite (Nov 2018)

Ist hyperspectral camera
Chandrayaan-1
- lunar mineral resources

- 630 km SSO, Inclination - 97.95°
- **Orbital period - 97m 26s**
- Repeat Interval - 133 orbits, Swath 30 km, Eq. crossing time 10.00 am
- **2 payloads - Spatial resolution - 30 m, Push-broom scanning mode**
- Visible NIR (VNIR)- spectral range of 0.4 to 0.95 μm with **60** continuous spectral bands with **10** nm width
- **SWIR - spectral range of 0.95 to 2.4 μm with a 10 nm bandwidth and **256** continuous spectral bands.**

RISAT (Radar Imaging Satellite)

First all-weather Earth Observation Satellite from ISRO - April, 2009

Active Microwave RS → cloud penetration and day-night imaging capability.

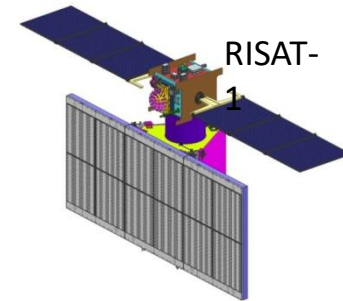
Sensor – Synthetic Aperture Radar (SAR).

After 26 Nov 2008 Mumbai attack, launch plan was modified to launch RISAT-2 before RISAT-1 .

RISAT-2 used X-band SAR sensor from Israel.

Applications - agriculture, forestry, soil moisture, geology, sea ice, coastal monitoring, object identification, and flood monitoring

Also used to track hostile ships at sea - military threat.



**RISAT-1 - Indigenously developed SAR -
April, 2012 , <1 m reso**

RISAT 2B - May 2019 - <50 cm reso

RISAT 2BR1 - Dec 2019 - about 0.35 m reso

EOS-1/RISAT-2BR2 - Nov 2020

EOS-4/RISAT-1A - Feb 2022

EOS-6 - Nov 2022

EOS-7 - Feb 2023

RISAT-1

Mass	1858 kg
Orbit	Circular Polar Sun Synchronous
Orbit Altitude	536 km
Orbit Inclination	97.552°
Orbit Period	95.49 min
Number of Orbits per day	14
Local Time of Equator Crossing	6:00 am / 6:00 pm

Few other major existing satellites

Satellite	Country	orbit	Sensors
ALOS	Japan	SSO	PRISM, PALSAR
Landsat	Us	SSO	OLI-2, TIRS-2
Sentinel	ESA	SSO	MSI
Terra	NASA	SSO	MODIS, MOPITT, MISR, ASTER
Aqua	NASA	SSO	MODIS, AIRS, AMSU
Jason	NASA & CNES	LEO	Altimeter
Radarsat	Canada	SSO	SAR c-band
Worldview	US	SSO	PAN, MS, CAVIS
GOES	NASA	GEO	
METEOSAT	Europe	GEO	

Few major decommissioned satellites

Quickbird
Worldview
IKONOS
EO
SPOT
CALIPSO
Envisat
TRMM

Remote sensing Applications

- Land use
 - Classification – waste land, wetland, cultivable land, lake etc
 - Wasteland management
- Agriculture
 - Crop monitoring and condition assessment
 - Crop canopy water stress
 - Crop yield estimates
 - Damage assessment
 - Pest and diseases outbreak
- Forestry
 - Inventory and updating
 - Encroachment
 - Habitat analysis
 - Fire damage
- Geology and exploration
 - Rock type
 - Landslide
 - Mineral exploration
 - Oil exploration
- Fisheries
 - Primary productivity
 - potential fishing zone
- Envi Monitoring
 - Air pollution
 - Desertification
 - Oil spill
- Water res management
 - dam site – catchment areas
 - ground water exploration
 - canal routing
- Snow and glacier studies
 - snow melt runoff
 - Retreat of glaciers
 - Polar studies
- Cartography
 - Maps at different scales
 - DEM
- Ocean/met applications
 - Ocean state forecast
 - Tropical cyclone
 - Storm surge
 - Tsunami
 - Weather forecast
- Coastal zone
 - Coastal erosion
 - Coral relief
 - Mangroves
- Disaster management
 - Floods, drought, cyclone, landslide, earthquake, forest fire
- Infrastructure & utilities
 - Road networks
 - Rail networks
 - Power grid network
 - Pipe lines
 - Urban sprawl
- National Security